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Overview of the CCITT Recommendations for Synchronous Digital Hierarchy

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ABSTRACT (unclassified)

This report contains an overview of the recent International Consultative Committee for Telephone and Telegraph (CCITT) Recommendations for the Synchronous Digital Hierarchy (SDH). The intention of this report is to give the reader, who has no prior knowledge of SDH, a simple insight into what SDH is and the associated terminology. This report does not provide an in depth analysis of SDH; for this the reader is referred to the appropriate CCITT Recommendations referenced in this report.

The aims of SDH is to provide a more cost effective service for the conveyance of broadband communications than that offered with the present Plesiochronous Digital Hierarchy (PDH) system and the capability of integrating the current incompatible PDH systems employed in Japan, North America and Europe into a single world-wide universal standard.

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SAMENVATTING (ongerubriceerd)

Dit rapport bevat een overzicht van het International Consultative Committee for Telephone and Telegraph (CCITT) aanbevelingen voor de Synchronous Digital Hierarchy (SDH). Het zal de lezer die geen kennis van SDH heeft een simpel inzicht in SDH geven. Dit rapport geeft geen gedetailleerde informatie over SDH. Voor meer gedetailleerde informatie wordt de lezer verwezen naar de CCITT aanbevelingen.

De doelstelling van SDH is het leveren van een kosteffectieve dienst voor breedband telecommunicatie en het integreren van de huidige incompatibele Plesiochronous Digital Hierarchy (PDH) systemen zoals toegepast in Japan, Noord-Amerika en Europa tot één wereldwijde standaard.

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LIST OF ABBREVIATIONS

AU	Administrative Unit
ANSI	American National Standards Institute
ATM	Asynchronous Transfer Mode
BISDN	Broadband Integrated Services Digital Network
CCITT	The International Telegraph and Telephone Consultative Committee
ETSI	European Telecommunications Standards Institute
IEEE	Institute of Electrical and Electronic Engineers
MAN	Metropolitan Area Networks
NNI	Network Node Interface
OAM	Operations, Administration and Maintenance
PDH	Plesiochronous Digital Hierarchy
POH	Path Overhead
PTR	Pointer
TU	Tributary Unit
TUG	Tributary Unit Group
SDH	Synchronous Digital Hierarchy
SOH	Section Overhead
SONET	Synchronous Optical Networks
STM	Synchronous Transport Module
TDM	Time Division Multiplexed
UNI	User-Network Interface
USA	United States of America
VC	Virtual Container

1 INTRODUCTION

In the mid eighties the International Consultative Committee for Telephone and Telegraph (CCITT) began studying the User-Network Interface (UNI) intended to support Broadband Integrated Services Digital Network (BISDN) services. During this study it was seen that the Network Node Interface (NNI), which determines the network structure, should be studied before the UNI because the UNI could not be standardised without the NNI. In addition to this problem, it was recognised that the differences between the currently employed three digital hierarchies, namely those of the United States of America (USA), Japan and Europe, would also create difficulties in arriving at a single world-wide UNI standard. At about the same time the USA reported on its work on Synchronous optical networks (SONET). Although initially SONET was not intended to be an international standard, the United Kingdom and Japan became very interested in the technique. This international interest triggered the CCITT to produce a set of ratified world-wide standards for the NNI, known as the Synchronous Digital Hierarchy (SDH), suited to the present three digital hierarchies, by the end of 1988.

2 SYNCHRONOUS DIGITAL HIERARCHY

2.1 General

Synchronous Digital Hierarchy (SDH) is the latest generation high order structure that will form the basis for a world-wide broadband networking standard. SDH is designed to replace the existing Plesiochronous Digital Hierarchy (PDH). The aim of SDH is to reduce the plant costs required to supply such a high order system by offering the following advantages over PDH:

- A world-wide standard; interworking between different hierarchies (e.g. North American and European)
- Easy access to low speed tributary signals and simplified multiplexing/ demultiplexing techniques
- Enhanced Operations, Administration and Maintenance (OAM) capabilities
- Easy growth to higher rates in step with the evolution of transmission technology
- Transverse compatibility between equipment of different manufacturers

SDH is CCITT's version of the Synchronous Optical Networks (SONET) standard developed by the American National Standards Institute (ANSI). The CCITT SDH standard is specified in Recommendations G.707 (SDH Bit Rates), G.708 (Network Node Interface for the SDH) and G.709 (Synchronous Multiplexing Structure) **[Ref. 1-3]**. As well as these Recommendations, other SDH related Recommendations are available namely; G.781, G.782 and G.783 (equipment specs.); G.784 (SDH network management functions) and G.957 and G.958 (optical and line interfaces). All of the above are available in the CCITT *Blue Books*, 1988. In addition to those above, other Recommendations are being produced concerning SDH Network Aspects. These are currently under preparation as G.sna 1 (architectures of transmission networks based on the SDH) and G.sna 2 (performance and management capabilities of transmission networks based on the SDH). These Recommendations should appear in the CCITT *White Books*, 1992. **[Ref. 4]**

2.2 Plesiochronous Digital Hierarchy

Before looking at SDH it is useful firstly to briefly look at the existing PDH. The PDH high order transmission structure is based on a point to point layered concept. There are currently three versions of the PDH structure, the European, North American and Japanese, therefore making PDH a non world-wide standard (see figure 1). Within Europe, the sub-hierarchy level 64kb/s circuits are Time Division Multiplexed (TDM) into a 2.048Mb/s hierarchy frame (Level 1). This in turn is multiplexed into an 8.448Mb/s hierarchy frame, which in turn is multiplexed into a 34.368Mb/s hierarchy frame, which finally is then multiplexed into an 139.264Mb/s hierarchy frame. At each hierarchical step, four of the previous frames are cyclic bit interleaved along with overhead information creating the new hierarchy frame (see figure 2). Such a multiplexing approach means that at each hierarchical level the original structure of the previous hierarchical level frames are lost and therefore so is their direct accessibility. To access the previous hierarchy frames and their information, it is necessary to totally demultiplex the higher order data stream. The example in figure 3 shows four 2Mb/s frames (A, B, C and D) being multiplexed into an 8Mb/s frame (X). This frame is then multiplexed with three other 8Mb/s frames to generate a 34Mb/s frame (Y). This is itself multiplexed with three other 34Mb/s frames, generating a 140Mb/s frame (Z). To gain access to one of the original 2Mb/s frames (e.g. A) it is necessary to demultiplex the 140Mb/s frame Z, so as to extract the 34Mb/s frame Y, thus accessing the 8Mb/s frame X, and so forth. The unwanted frames at each hierarchical level have then to be re-multiplexed with another like frame so as to generate a new frame at the next level up (i.e. X^1, Y^1 and Z^1) The drop and inserting technique makes PDH complicated and requires a considerable amount of support hardware. The same is equally true in the Japan and North American systems.

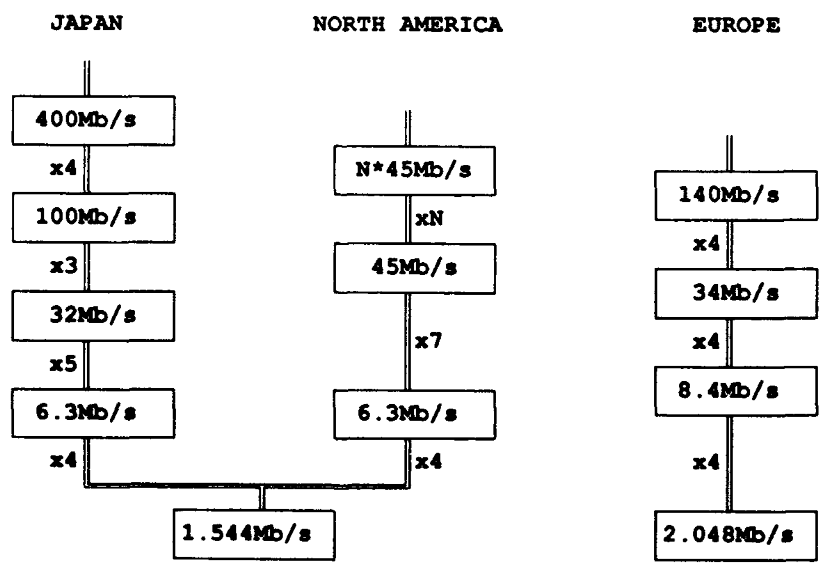
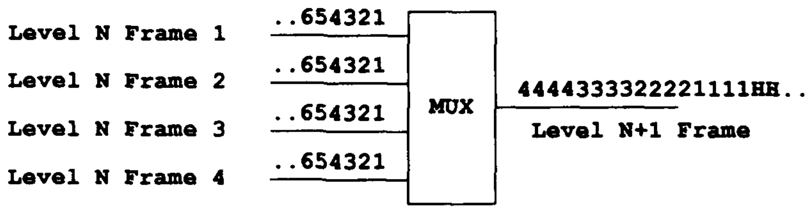


Fig. 1: Plesiochronous Digital Hierarchies



H = Overhead bits

Fig. 2: PDH Cyclic Bit Interleaving

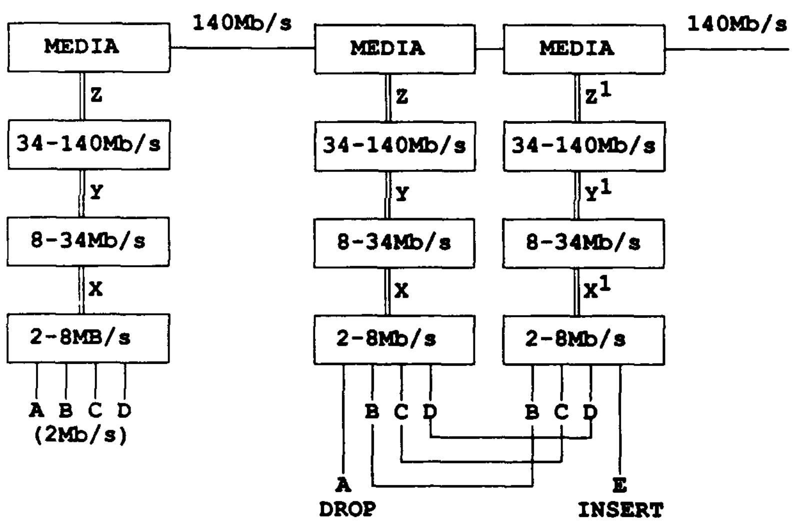


Fig. 3: PDH Drop and Insert Technique

2.3 Synchronous Digital Hierarchy

The SDH high order transmission structure is not bound by the multiplexing constraints of PDH because all the different data stream types are assembled into what is known as a Container. These Containers come in various sizes (i.e. capacity) and it is possible to assemble the smaller Containers into the larger Containers. These Containers are then synchronised into a single payload known as a Synchronous Transport Module (STM). Each Container type has an associated Pointer. These Pointers indicate the exact location of the Container within the STM in the case of the larger Containers or where a smaller Container lies within a larger Container. This pointer method allows for the dropping or inserting of single or multiple 2.048Mb/s data streams simply and flexibly without the need for several demultiplexing stages (see figure 4). In addition to this, SDH is designed to support all three of the above PDH hierarchies in the one STM.

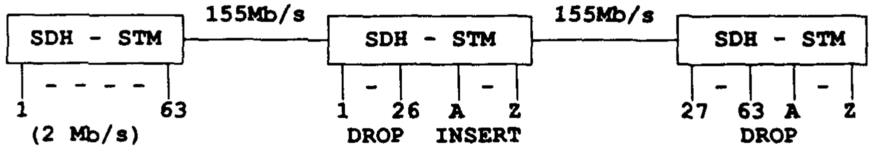


Fig. 4: SDH Drop and Insert Technique

The following chapters briefly describe SDH based on the contents of the three CCITT Recommendations referenced above. This section shall give the reader an insight into the bit rates supported, the multiplexing method, frame structure and the terminology used. Readers are also referred to the respective CCITT Recommendations for more detailed information.

2.4 SDH Bit Rates

The CCITT Recommendations on SDH provide a framework for the mapping and multiplexing of the plesiochronous tributary rates as indicated in CCITT Recommendation G.702 **[Ref. 5]** and for future broadband signals (i.e. ATM or IEEE 802.6 as proposed for MANs) in a synchronous signal. The recommended, first level, SDH transmission rate is 155.520Mb/s and is known as a *Synchronous Transport Module* (STM-1). Higher level transmission rates are also mentioned by CCITT and these are denoted by their corresponding multiplication factor of the first level rate as follows:

STM-4	(x4)	622.080Mb/s
STM-8	(x8)	1244.160Mb/s
STM-12	(x12)	1866.240Mb/s
STM-16	(x16)	2488.320Mb/s

The last three transmission rates within CCITT Recommendation G.707 are still for further study. The various plesiochronous interface rates supported by SDH are listed in Table 1.

INTERFACE RATE	CCITT REF.
1.544Mb/s	C-11
2.048Mb/s	C-12
6.312Mb/s	C-21
8.448Mb/s	C-22
34.368Mb/s	C-31
44.736Mb/s	C-32
139.264Mb/s	C-4

Table 1: SDH Bit Rates

The references C-nx defines the contents of the SDH Container (C), described later, where n denotes the "equivalent" plesiochronous hierarchical level and x the bit rate at that hierarchical level when more than one bit rate is supported.

2.5 SDH Multiplexing Elements

Figure 5 shows the relationship between the SDH multiplexing elements, defined below, which contain the various signals to be carried in the STM-1 payload for transmission at the Network Node Interface (NNI).

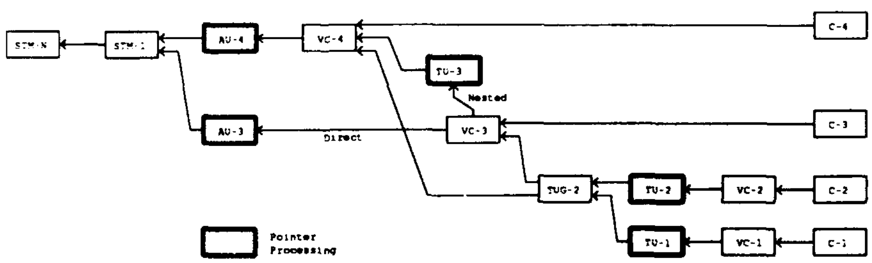


Fig. 5: General SDH Multiplexing Structure

2.5.1 Container C-n

The Container element C-n, where n = 1 to 4, is a unit payload of capacity dimensioned to carry the bit rates currently defined in G.702. It may also provide capacity for the transport of broadband signals not contained in G.702 or yet defined.

2.5.2 Virtual Container VC-n

There are two types of Virtual Container (VC-n):

Basic Virtual Container, VC-1 and VC-2. These elements contain a single C-1 or C-2 element respectively plus the basic Virtual Container Path Overhead (POH).

Higher order Virtual Container, VC-3 and VC-4. These elements contain a single C-3 or C-4 element respectively or an assembly of Tributary Unit Groups (see para. 2.5.4) or an assembly of Tributary Units (see para. 2.5.3), plus the Virtual Container POH appropriate to that level.

The Virtual Container POH provides for communication between the point where the VC was assembled and the point where it is to be disassembled (see figure 6). There are two types of POH; one for the basic Virtual Container and the other for the higher order Virtual Container. Both types include such functions as Virtual Container path performance monitoring, signal for maintenance purposes and alarm status indications. The higher order POH also includes multiplex structure indications (i.e. composition of VC-3 and 4).

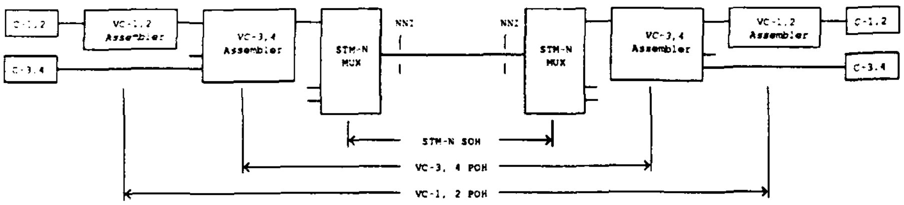


Fig. 6: SDH Path Overheads

2.5.3 Tributary Unit TU-n

The Tributary Unit (TU-n) contains a Virtual Container (VC-1, 2, or 3) plus a Tributary Unit Pointer (TU-n PTR). The Tributary Unit Pointer indicates the phase alignment of the Virtual Container with respect to the POH of the next higher level Virtual Container in which it resides (e.g. VC-3, 4). The location of the Tributary Unit Pointer itself is fixed within the higher level POH, (see also STM-1 Frame Structure and figure 9b).

2.5.4 Tributary Unit Group TUG-n

This element contains an homogeneous assembly of TU-1s or single TU-2 in the case of a TUG-2, or an homogeneous assembly of TUG-2s or single TU-3 in the case of a TUG-3.

2.5.5 Administrative Unit AU-n

An Administrative Unit (AU-n) contains a Virtual Container (VC-3, or 4) plus an Administrative Unit Pointer (AU-n PTR). The VC-n associated with each AU-n does not have a fixed phase with respect to the STM-1 frame. The Administrative Unit Pointer therefore indicates the location of the first byte and the phase alignment of the respective Virtual Container with respect to the STM-1 frame. The Administrative Unit Pointer itself does have a fixed location in the STM-1 frame (see also STM-1 Frame Structure and figure 9a).

2.5.6 Synchronous Transport Module Level 1 STM-1

A Synchronous Transport Module level 1 is the basic building block of the SDH and it contains either one AU-4 or multiple AU-3s, together with the Section Overhead (SOH) which is described later in para. 2.6.

2.5.7 Synchronous Transport Module Level N STM-N

This element defines the Nth level of the SDH and contains N synchronously multiplexed STM-1 signals, for example STM-4, which is described in para. 2.7

2.6 Synchronous Transport Module STM-1 Frame Structure

The STM frame structure is shown in figure 7. The frame is divided into 270 columns (bytes) by 9 rows. These gives a total size of 2430 bytes, (although not all the bytes are available for Data). This results in a transmission rate of 8000 STM-1 frames per second (i.e. 155.520/[2430*8]), with a STM-1 frame length of 125μs, all of which is comparable with PDH. The frame structure has three main areas:

Section Overhead
Administrative Unit Pointers
STM-1 Payload

2.6.1 Section Overhead

The Section Overhead capacity (rows 1-3 and 5-9 of columns 1-9) is added to either an AU-4 or an assembly of AU-3 elements to create the complete STM-1 frame. This overhead contains the STM-1 framing , as well as performance monitoring and other maintenance and operational functions. These functions can be modified or added too, (e.g. intermediate regenerator monitoring, protection switching control) for various element configurations without disassembly of the STM-1 frame.

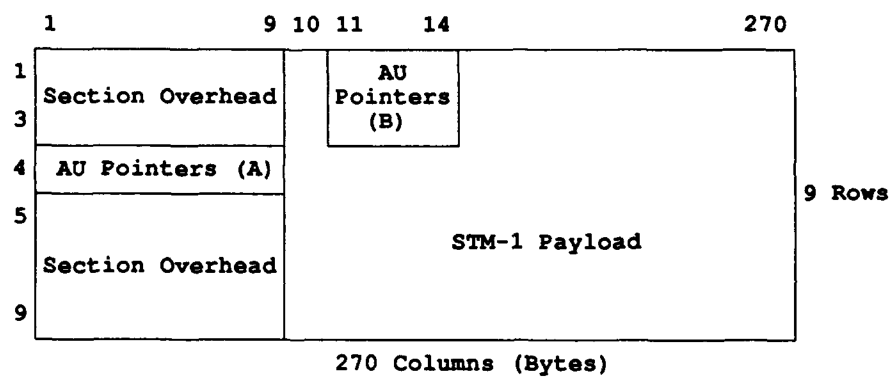


Fig. 7: STM-1 Frame Structure

2.6.2 Administrative Unit Pointers (AU)

The AU pointers are located in row 4 of columns 1-9 and row 1-3 of columns 11-14. Their position for the different assembled STM-1 payload's is as listed in Table 2. Its function is as described previously.

AU TYPE	POINTER LOCATION
31	Areas A and B
32	Area A
4	Area A

Table 2: Location of AU Pointers

2.6.3 STM-1 Payload

The STM-1 payload capacity can support the following types and numbers of AUs; one AU-4, or three AU-32s, or four AU-31s, the last two options being the direct method (see figure 9a). An AU-4 has the payload capacity of 139.264Mb/s; an AU-32, has a capacity of 44.736Mb/s and an AU-31 has a capacity of 34.368Mb/s. The AU-4 can also be used to carry via the VC-4, three TU-32s or four TU-31s in a nested arrangement as shown in figure 9b. The actual mapping of the individual bytes of the respective elements into the STM-1 payload is specified in CCITT Recommendation G.709. As this is a detailed subject it will not be addressed in this paper and therefore the reader is referred to G.709. Within the STM-1 frame it is not always the case or necessary, at each interface rate, for the overhead as well as the payload capacity to be completely full. It is possible for both to be partially filled as in the case for data rates below 155.520Mb/s, thus allowing for further insertions later in the network.

2.7 Synchronous Transport Module STM-4 Frame Structure

The next SDH level specified in the CCITT Recommendations above level 1 is that of level 4, STM-4, operating at 622.080Mb/s. This level is formed by single byte interleaving four STM-1s as shown in figure 8a resulting in a STM-4 frame structure is shown in figure 8b.

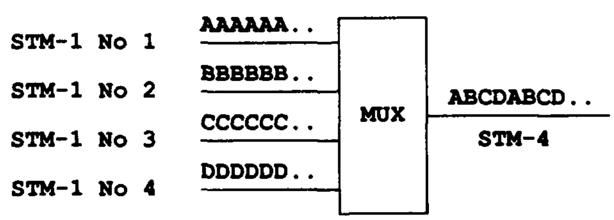


Fig. 8a: STM-4 Single Byte Interleaving

Using the single byte interleaving technique illustrated in figure 8a the STM-4 frame is constructed such that the first byte of the STM-4 frame is the first byte of the STM-1 No 1 frame, the second byte is the first byte of STM-1 No 2 frame, the third the first of the STM-1 No 3 etc. Before the STM-1 frames are byte interleaved their associated SOH and AU-n pointers are adjusted in value so as to indicate the start of the associated STM-1 VC(s) with respect to their new position in the STM-4 frame.

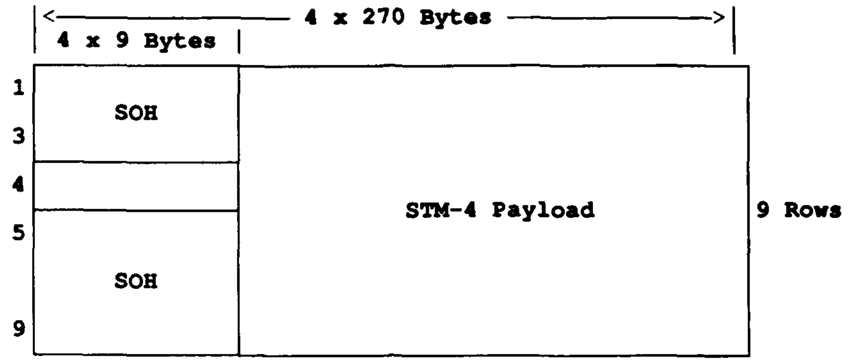
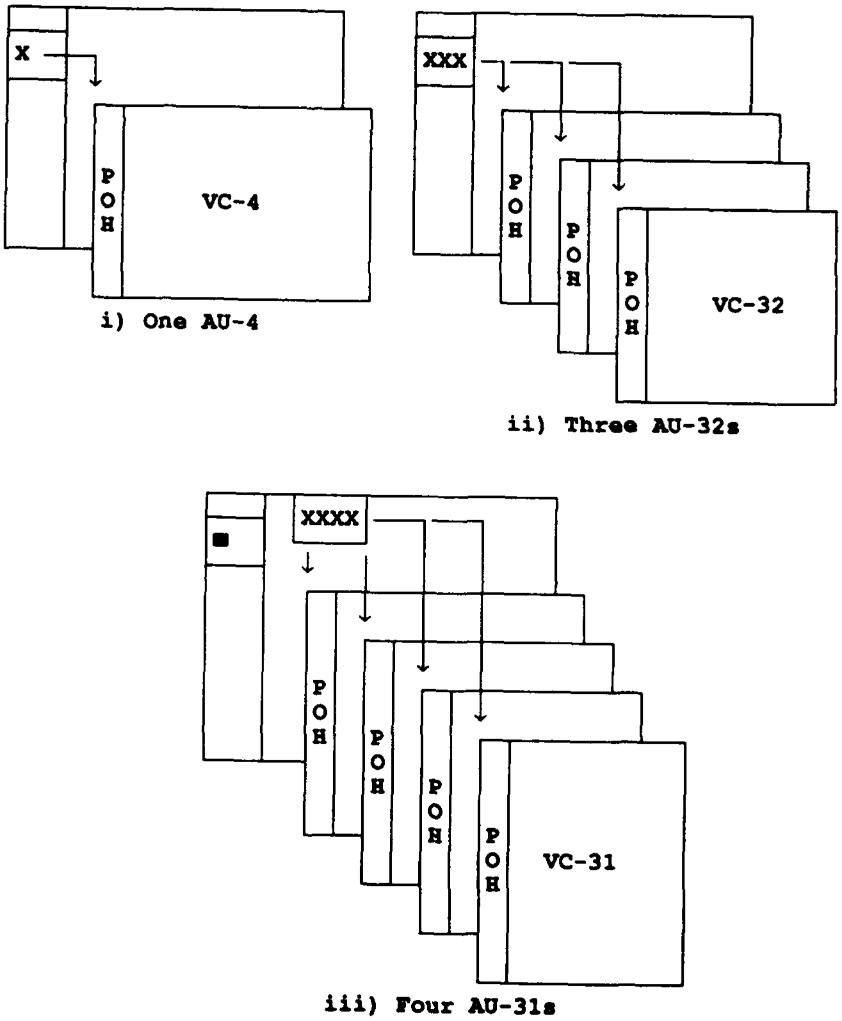


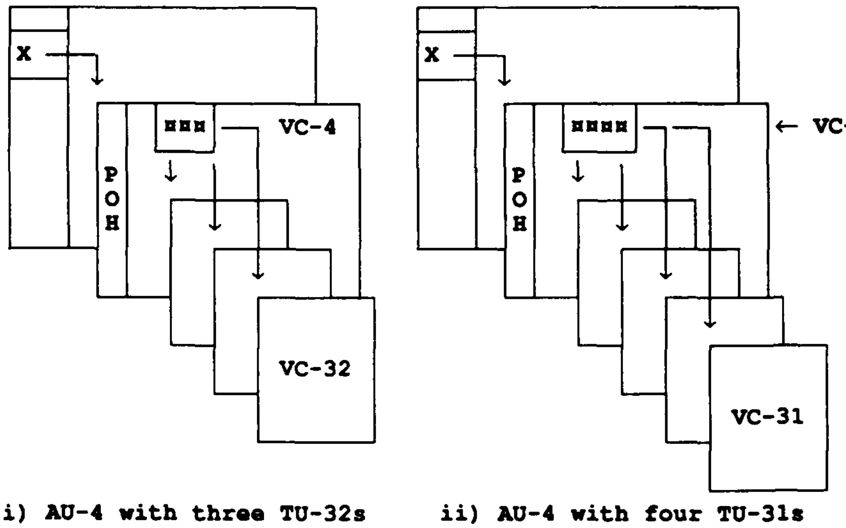
Fig. 8b: STM-4 Frame Structure

The STM-4 frame structure is divided into 4*270 columns (bytes) by 9 rows. These gives a total size of 9720 bytes, again with a transmission rate of 8000 frames per second (i.e. 622.080/[9720*8]) and a frame length of 125μs as per the STM-1 frame. Within a STM-4 frame it is possible to mix STM-1 frames containing AU-3s and STM-1 frames containing AU-4s as illustrated in figure 9a.



X = AU pointer location
■ = AU pointer (Null Pointer Indication)
POH = Path Overhead

Fig. 9a: Administrative Units (AUs) in a STM-1 Frame



X = AU pointer location
¤ = TU-3 pointer location
POH = Path Overhead

Fig. 9b: Use of AU-4 to carry TU-3s

2.8 European Telecommunications Standards Institute

Since the approval of the SDH standards by the CCITT, European nations have been meeting under the umbrella of the European Telecommunications Standards Institute (ETSI) so as to adopt an agreed European standard on SDH. These meetings have culminated in an agreed multiplexing scheme approved by both the ETSI and CCITT Study Group XVIII (see figure 10). The adoption of this multiplex route, which is slightly different than that detailed in CCITT Recommendation G.709, allows the European standard to support both 34.368 and 44.736Mb/s as well as 1.544Mb/s providing maximum compatibility with the other world regions. Figure 11 shows an example of how a 2.048Mb/s PDH signal is multiplexed beginning with the SDH Container (C-12) element into the final STM-1 frame using one of the ETSI multiplex routes. Figure 12 shows how these various elements including the Pointers and Path Overheads depicted in figure 11 are mapped into each other, starting from the top (i.e. STM-1) and working down.

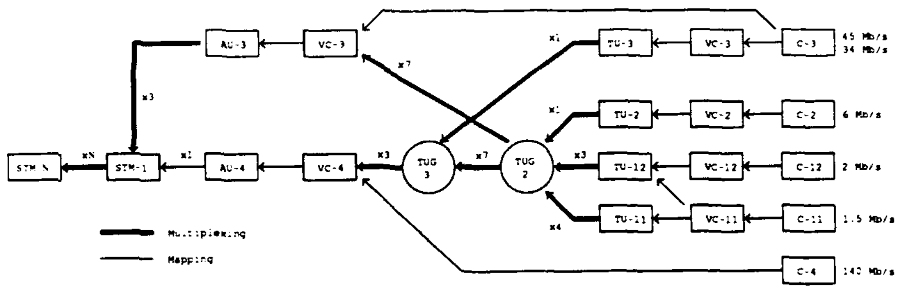


Fig. 10: ETSI SDH Multiplexing Structure

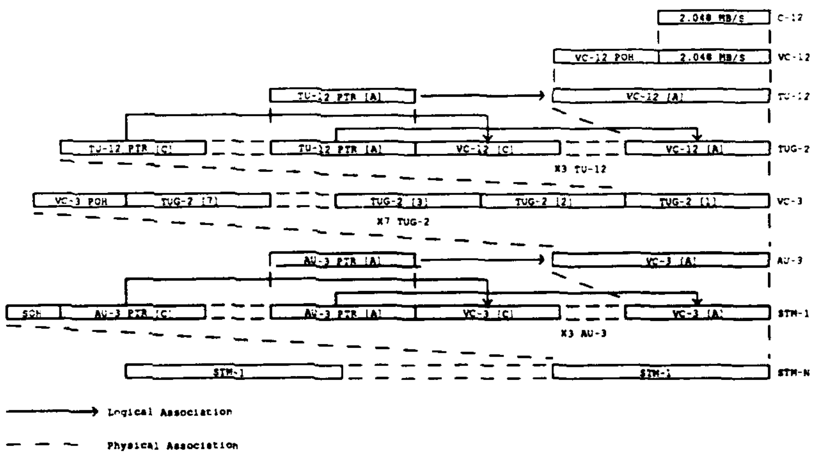
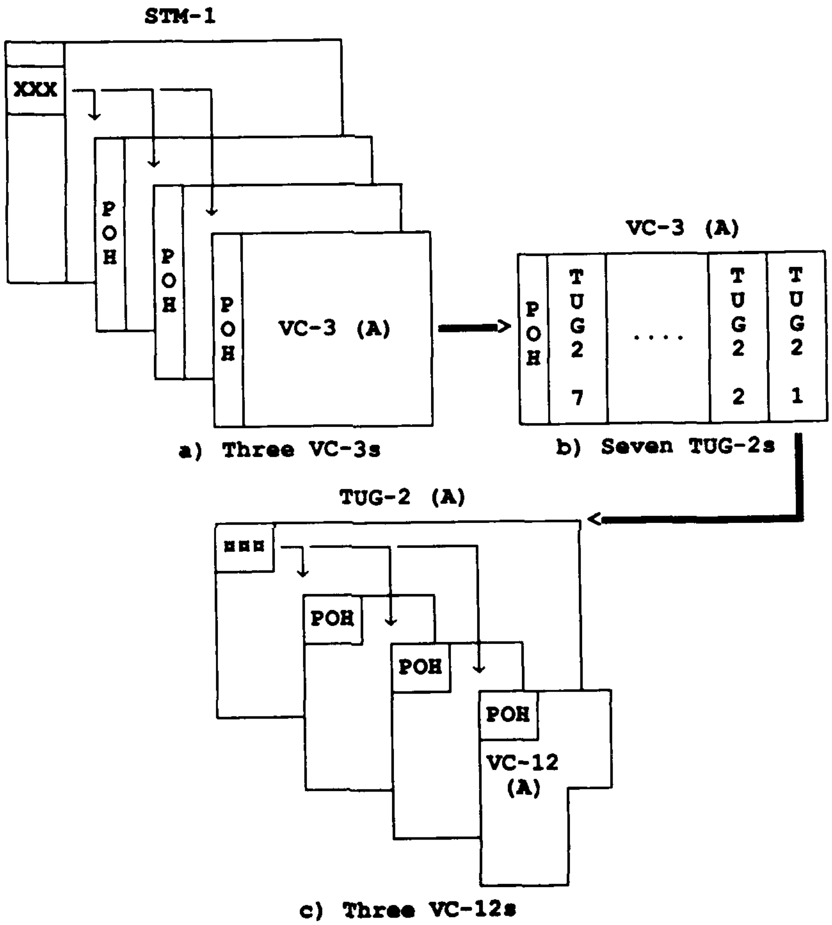


Fig. 11: C-12 (2.048Mb/s) Multiplexing Method



X = AU-3 pointer location
¤ = TU-12 pointer location
POH = Path Overhead

Fig. 12: C-12 (2.048Mb/s) Mapping Method

3 CONCLUSIONS

This report has studied the recently introduced CCITT Recommendation on the Synchronous Digital Hierarchy (SDH) for use between Network Node Interfaces (NNI) as part of the evolving Broadband Integrated Services Digital Network (BISDN) services of the future. The conclusions reached are that SDH:

1 - offers the capability of integrating the current Plesiochronous Digital Hierarchy systems employed in Japan, North America and Europe into a single world-wide standard

2 - in connection with the above, because it supports the currently employed bit rates it can work with and along side the existing PDH systems allowing its full implementation to be a transitional one as old equipment is replaced.

3 - SDH provides a more cost effective approach than PDH because of its capability of directly accessing the lower bit rate signals from the higher bit rates by use of the Pointers, therefore reducing the need for large amounts of drop and inserting multiplex/demultiplex equipment

4 - SDH is still in its infancy and if it is to realise its full potential there is further work still to be done and further recommendations to be produced, especially in the following areas:

The establishment of "agreed upon" equipment and management standards

The availability of such network elements as terminal multiplexers, insert/drop multiplexers, etc. as well as a management system to support an SDH network.

4 REFERENCES

[1] CCITT Recommendation G707
Synchronous Digital Hierarchy Bit Rates
Blue Book Volume III - Fascicle III.4
IXTH Plenary Assembly
Melbourne 14-25 November 1988

[2] CCITT Recommendation G708
Network Node Interface for the Synchronous Digital Hierarchy
Blue Book Volume III - Fascicle III.4
IXTH Plenary Assembly
Melbourne 14-25 November 1988

[3] CCITT Recommendation G709
Synchronous Multiplexing Structure
Blue Book Volume III - Fascicle III.4
IXTH Plenary Assembly
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[4] An Overview of Emerging CCITT Recommendations for the
Synchronous Digital Hierarchy: Multiplexers, Line
Systems, Management and Network Aspects
IEEE Communications Magazine
August 1990 - pages 21-25

[5] CCITT Recommendation G702
Digital Hierarchy Bit Rates
Blue Book Volume III - Fascicle III.4
IXTH Plenary Assembly
Melbourne 14-25 November 1988

5 ADDITIONAL MATERIAL

The following is a list of additional source material which may be of interest to the reader:

[1] CCITT Standardisation of Network Node Interface
of Synchronous Digital Hierarchy
IEEE Communications Magazine
August 1990 - pages 15-20

[2] Evolution of the Italian Telecommunication Network
Towards SDH
IEEE Communications Magazine
August 1990 - pages 44-49

[3] Synchronous Digital Transmission Systems Based
on CCITT SDH Standard
IEEE Communications Magazine
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[4] The Evolution of SDH: A View From Telecom New Zealand
IEEE Communications Magazine
August 1990 - pages 60-66

[5] The New CCITT Synchronous Digital Hierarchy:
Introduction and Overview
British Telecommunications Engineering
Vol. 10, July 1991 - pages 104-107

[6] SDH Multiplexing Concepts and Methods
British Telecommunications Engineering
Vol. 10, July 1991 - pages 108-115

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14 SUPPLEMENTARY NOTES

15 ABSTRACT (MAXIMUM 200 WORDS, 1044 POSITIONS)
THIS REPORT CONTAINS AN OVERVIEW OF THE RECENT CONSULTATIVE COMMITTEE FOR TELEPHONE AND TELEGRAPH (CCITT) RECOMMENDATIONS FOR THE SYNCHRONOUS DIGITAL HIERARCHY (SDH). THE INTENTION OF THIS REPORT IS TO GIVE THE READER, WHO HAS NO PRIOR KNOWLEDGE OF SDH, A SIMPLE INSIGHT AS TO WHAT SDH IS AND THE ASSOCIATED TERMINOLOGY. THIS REPORT DOES NOT PROVIDE AN IN DEPTH ANALYSIS OF SDH, FOR THIS THE READER IS REFERRED TO THE APPROPRIATE CCITT RECOMMENDATIONS REFERENCED IN THIS REPORT.
THE AIMS OF SDH IS TO PROVIDE A MORE COST EFFECTIVE SERVICE FOR THE CONVEYANCE OF BROADBAND COMMUNICATIONS THAN THAT OFFERED WITH THE PRESENT PLESIOCHRONOUS DIGITAL HIERARCHY (PDH) SYSTEM AND THE CAPABILITY OF INTEGRATING THE CURRENT INCOMPATIBLE PDH SYSTEMS EMPLOYED IN JAPAN, NORTH AMERICA AND EUROPE INTO A SINGLE WORLD-WIDE UNIVERSAL STANDARD.

16 DESCRIPTORS DATA TRANSMISSION PROTOCOLS	IDENTIFIERS CCITT SYNCHRONOUS DIGITAL HIERARCHY

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